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# Subsurface Morphologic Changes of ND:YAG Laser-Etched Enamel

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***Background and Objective:*** **Etching the enamel surface with a Nd:YAG dental laser produces impact craters with cavities, micropores, and microfissures. This in vitro SEM study examined laser-etched enamel to determine the pattern and extent of subsurface changes.**
***Study Design/Materials and Methods:*** **The facial surface of 10 maxillary central incisor teeth were coated with a black initiator and laser-etched with a pulsed Nd:YAG laser (1.06λ, 75 mJ, 15 Hz, 320 μm fiber, 94 J/cm$^2$ fluence). The facial surface of five teeth were plastic-embedded under a low vacuum, then demineralized in 10% formic acid. The other teeth were split incisoapically. All samples were prepared for SEM.**
***Results:*** **Examination of the plastic impressions showed a delicate interlacing pattern of thin partitions and small knob-like expansions. Examination of the split teeth showed the penetration of microfissures into the enamel estimated at 10 μm.**
***Conclusion:*** **These subsurface alterations may provide space for the infiltration and mechanical retention of dental resin. Lasers Surg. Med. 21:193–197, 1997.** **© 1997 Wiley-Liss, Inc.**

**Key words: laser; Nd:YAG; enamel; etching; subsurface**

## INTRODUCTION

Laser irradiation has been used to investigate the morphologic and structural changes induced on the enamel and dentin of teeth. Lasers have been studied for use in the detection [9,25,26] and removal of enamel caries [5,6,28] and cavity preparation [22,29,30,32,34], treating pits and fissures [10,16], in etching the surface for the bonding of dental resin [11,13,20,21,23,24], and in altering the calcium hydroxyapatite crystalline structure to increase caries resistance [7,15]. The types of lasers used in these studies have included: ruby [1,2], carbon dioxide [3–12,27], Nd:YAG [12–23], $CO_2$-Nd:YAG [12,23], argon-ion [24–27], excimer-dye [27], argon-fluoride excimer [28,29], krypton-fluoride excimer [30], xenon-chloride excimer [31], Er:YAG [32,33], Nd:YLF [34], and semiconductor [35].

The changes in the enamel are dependent upon the wavelength of the laser, emission mode of the laser (pulsed or CW), the energy density received at the surface, duration of exposure, and the nature of the substance absorbing the laser energy. Therefore, different lasers have produced various results. The effects on the morphology of the surface can range from no apparent surface alteration to rather dramatic melting, resolidification, and evaporation of the enamel. In particular, the Nd:YAG laser produces shallow craters with numerous microcavities, micropores, and microfissures as reported by Hess [13] and others [14–17,22,24]. These studies, however, only reported changes that occurred morphologically at the surface. The very nature of bubbles, pores, and cracks suggests an extension of these features beneath the surface.

The purpose of this study was to investigate the pattern and extent of the subsurface changes in Nd:YAG laser-irradiated enamel by examining

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a detailed plastic impression of the surface with scanning electron microscopy.

## MATERIALS AND METHODS

Intact, noncarious human maxillary central incisor teeth were collected in deionized water and grossly debrided of all soft tissues. Each tooth was examined under a dissecting microscope, and those with gross surface defects or areas of decalcification on the facial surface were discarded. Ten teeth were selected and further cleaned with a nonfluoride pumice/water mixture using a prophy cup attached to a low-speed handpiece.

The selected site on the facial surface of the crowns were coated with black laser initiator (Black Sumi Ink KF2, Yasutomo, San Francisco, CA) using a fine brush to enhance energy absorption and etched with a pulsed Nd:YAG laser (American Dental Technologies, Southfield, MI) according to Hess [13]. The surface area covered by the initiator ranged from ~2.5–3.5 mm in diameter. The coated surfaces were irradiated for an average of 9 seconds at 75 mJ at a repetition rate of 15 Hz using a 320 μm optical fiber. This provided an energy density at the surface of 94 J/cm$^2$. The average number of pulses was 135. The fiber tip was held lightly against the surface and passed over the initiator-covered enamel until the initiator was removed. The adjacent noncoated and enamel served as both irradiated and nonirradiated control surfaces.

After laser-etching, five teeth were dehydrated and embedded in plastic (Bio-Plastic, Ward's, Rochester, NY) under a low vacuum. After curing, the blocks were cut with a diamond disk so that the lased facial portion of the teeth was obtained. The teeth were removed from the plastic by demineralization in 10% formic acid. The removal of the tooth structure provided a detailed negative plastic impression of the lased site. Each plastic block was then mounted and coated with gold-palladium. The other five teeth were split with a chisel and mallet from the incisal edge lengthwise such that the free fracture line passed through the laser irradiated site. The teeth were dehydrated, mounted, and coated with gold palladium. All of the samples were examined in a Joel (Peabody, MA) JSM-840A scanning electron microscope operating at 5–20 KV.

## RESULTS

Previous work [13] has shown that the SEM appearance of the laser-etched enamel surface is an irregular overlapping pattern of distinctive craters each with a diameter of ~200–300 μm (Fig. 1). This region was sharply delimited to the area that had been coated with the black laser initiator. Abundant bubble-like cavities, ranging from 0.5–1.5 μm in diameter, and numerous microcavities and micropores <0.5 μm in diameter were present throughout each laser-irradiated crater. In addition, an irregular, angular pattern of microfissures appeared throughout the laser-irradiated area (Fig. 2). These microfissures extended beyond the initiator-coated margin (Fig. 3) into the halo zone where they quickly disappeared. The enamel surface beyond the halo zone appear to be morphologically nonreactive.

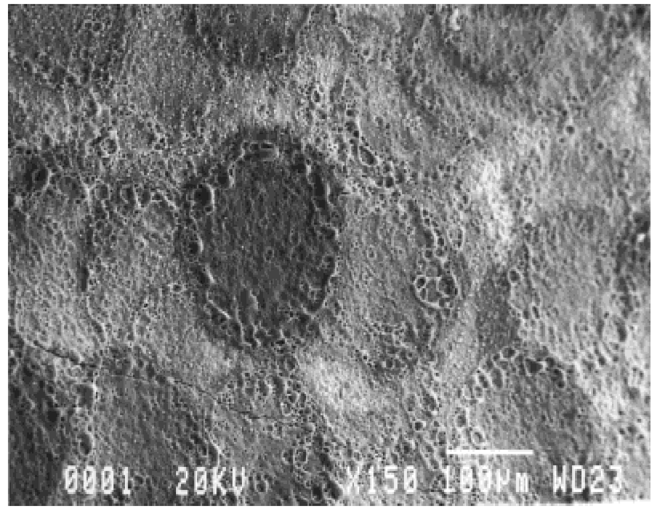


Fig. 1. Scanning electron micrograph of the laser-etched enamel surface. Single impact craters are clearly distinguished. ×150; bar = 100 μm.

In a SEM micrograph under low magnification, the plastic impression of the facial surface of the incisor showed a well-defined, laser-irradiated region. The detailed pattern of perikymata were also evident as they extended across the facial surface of the crown (Fig. 4). Greater magnification of the central region of the irradiated region revealed a delicate pattern of interconnecting partitions or septa (Fig. 5). The pattern of these septa extended from the margin of the defined edge of the coated region for a short distance and quickly disappeared. The angular nature of these partitions and the extension into the halo zone is similar to that of microfissures as seen in Figure 3. The partitions, and therefore, the microfissures, have a depth estimated to be ~10 μm or greater (Fig. 6). Numerous small expansions were noted among the partitions (Fig. 7)

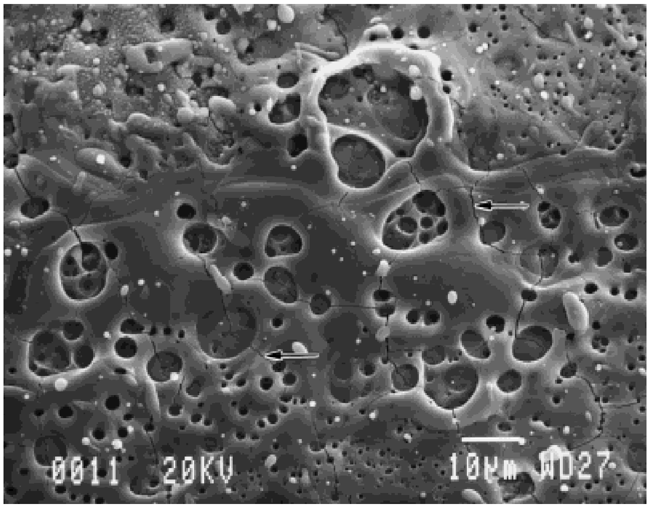


Fig. 2. A high magnification of a crater shows numerous bubble-like cavities of variable size and a larger number of smaller pores. Microfissures are evident (arrows). The angular pattern of microfissures should be noted. ×1000; bar = 10 μm.

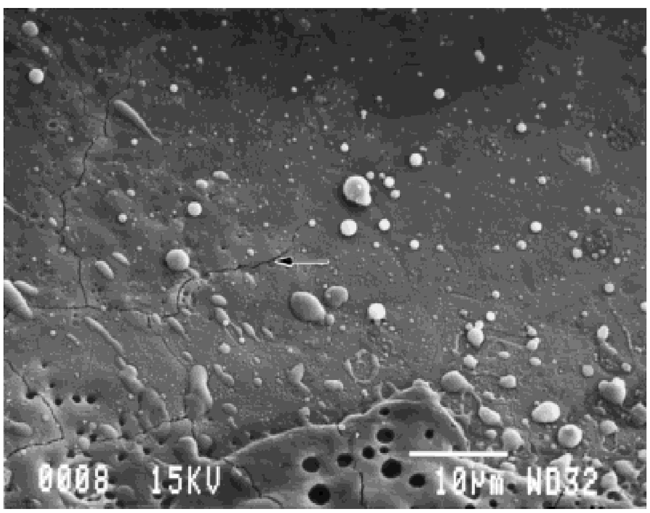


Fig. 3. A high magnification of the edge of the coated, laser-irradiated region shows the extension of the microfissures toward the noncoated surface (arrow). It should be noted that these structures diminish in size until they disappear. The ejected resolidified enamel can be seen on the surface as small elevated mounds. ×1700; bar = 10 μm.

and may represent the microcavities visible within the larger cavities in a surface view.

Scanning electron microscopic examination of the split samples showed the fractured edge of the laser-etched surface. Many undercuts and other irregular regions were created upon resolidification of the molten enamel matrix. These features appeared to be confined to the surface 5–10 μm layer of resolidified enamel. Microfis-

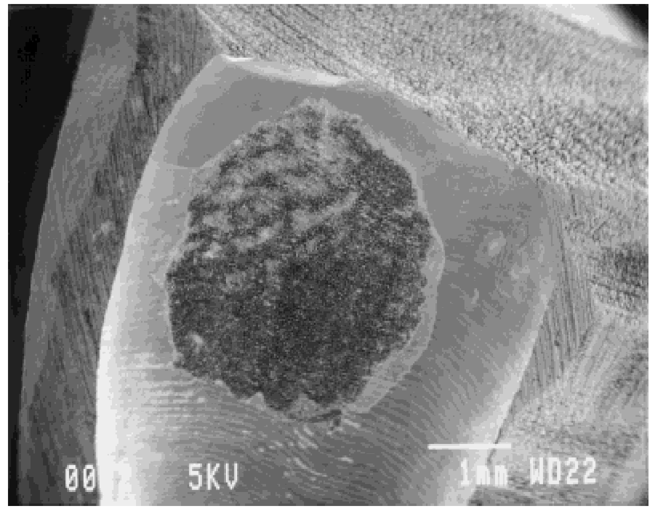


Fig. 4. This low magnification SEM photomicrograph shows a plastic impression of the facial surface of a maxillary central incisor that was coated and laser irradiated. A distinctive line separates the region of the tooth that had been coated with the black initiator. The perikymata on the surface can be seen as faint lines across the facial surface of the impression. ×15; bar = 1 mm.

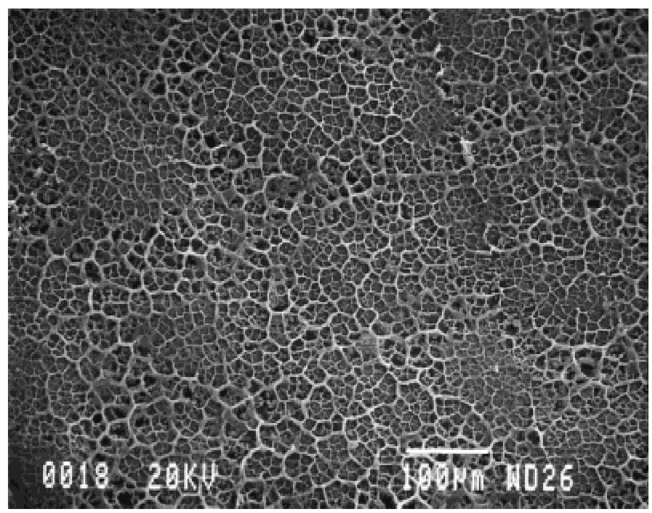


Fig. 5. Elaborate honeycombed pattern of partitions can be seen in this SEM photomicrograph. It should be noted that the pattern of the partitions reflects a similar pattern of surface microfissures seen in Figure 2. ×150; bar = 100 μm.

sures extended into the underlying enamel for an estimated distance of 10 μm (Fig. 8).

## DISCUSSION

Laser-irradiated enamel demonstrates different degrees of modification induced by the absorption of light energy. The Nd:YAG laser [13–17], as well as other types, produces morphologic

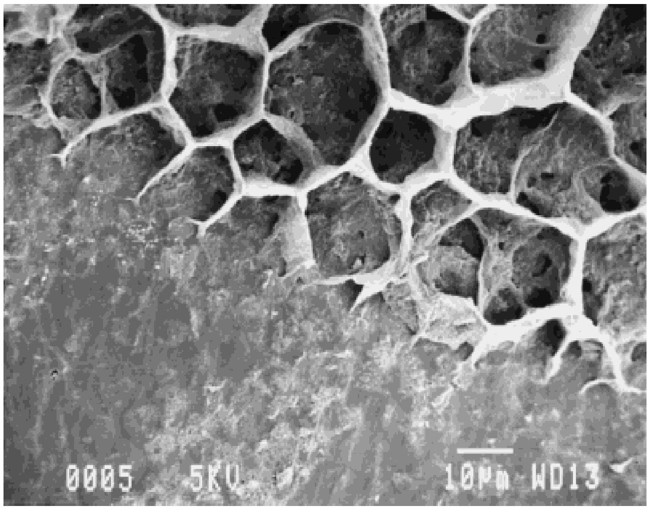


Fig. 6. This high magnification SEM photomicrograph shows the honeycombed structure on the edge of the laser-irradiated region. The formation of the partitions is sharply demarcated. Note the rapid disappearance of the partitions toward the noncoated region of the surface. ×1000; bar = 10 μm.

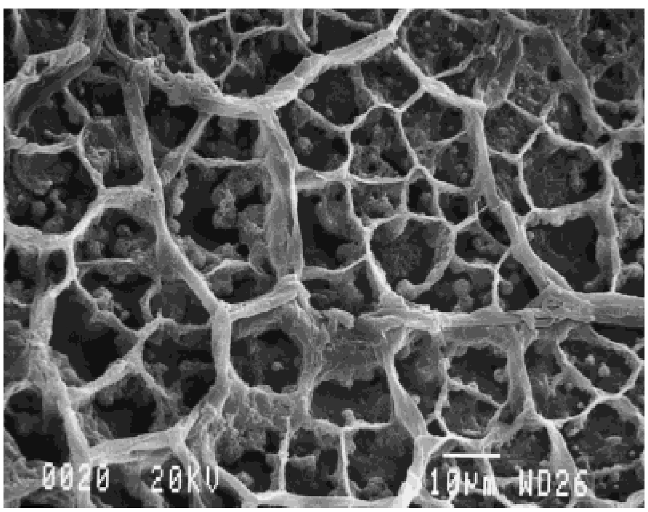


Fig. 7. This detailed SEM view of the plastic impression shows the complexity of the partitions. Note the many beads along the partitions. These may represent the microcavities visible as a surface feature in Figure 2. ×1000; bar = 10 μm.

changes described as crazing, cracks or (micro)fissures, (micro)cavities or pits, and (micro)pores. The black initiator serves as a selective medium for the photo-absorption of the Nd:YAG laser energy in order to affect surface changes in enamel. The alterations produced may be the result of outgassing of vaporized water and other gases from the superheated enamel matrix. In contrast, the distinctive angular pattern of the microfissures may be related to the rapid cooling of the thin superficial layer of molten enamel or to the pat-

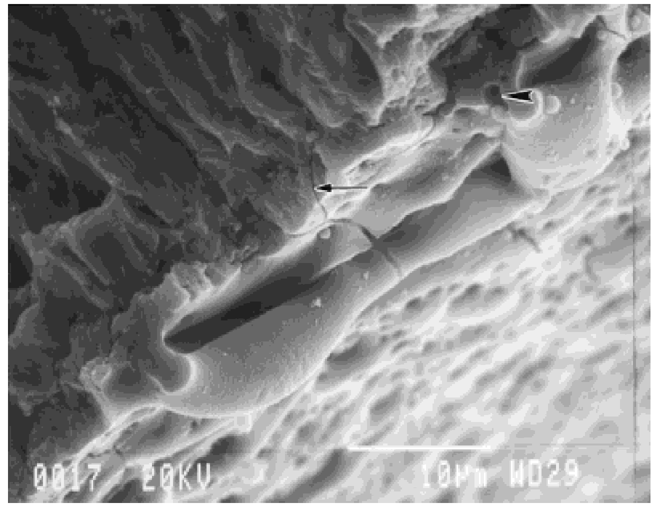


Fig. 8. SEM micrograph of a fractured edge of a laser-etched enamel surface. A retentive undercut is seen within the resolidified enamel. The presence of a narrow microfissure should be noted as well as its extension into the underlying enamel (arrow). A small micropore opening can be seen as a microcavity (arrowhead). ×2500; bar = 10 μm.

tern of the underlying enamel rods or to both. In two clinical studies, the Nd:YAG [20] and the $CO_2$ [11] lasers were used to etch the enamel surface in an attempt to provide a site favorable for the bonding of dental resin. The bond strength of a composite resin to laser-etched enamel depends on the physical complexity of the interface between the resin and the enamel surface. The reported morphological surface changes as well as the subsurface extension of the microfissures may provide such an interface for the penetration and mechanical retention of dental resin.

This study examined plastic impressions of Nd:YAG laser-etched enamel surfaces to determine the extent of subsurface structural changes. The unique bubble-like surface topography of laser-etched enamel as well as the formation of microfissures may provide the mechanical interface required for the retention of resin materials.

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## REFERENCES

1. Gordon TE Jr. Some effects of laser impacts on extracted teeth. J Dent Res 1966; 45(2):372–375.

2. Lobene R, Fine S. Interaction of laser radiation with oral hard tissues. J Pros Dent 1966; 16(3):589–597.
3. Stern RH, Vahl J, Sognnaes RF. Lased enamel: Ultrastructural observations of pulsed carbon dioxide laser effects. J Dent Res 1972; 51(2):455–460.
4. Nelson DGA, Wefel JS, Jongebloed WL, Featherstone JDB. Morphology, histology and crystallography of human dental enamel treated with pulsed low-energy infrared laser radiation. Caries Res 1987; 21(5):411–426.
5. Nelson DGA, Shariati M, Glena R, Shield SCP, Featherstone JDB. Effect of pulsed low energy infrared laser irradiation on artificial caries-like lesion formation. Caries Res 1986; 20(4):289–299.
6. Melcer J. Latest treatment in dentistry by means of the $CO_2$ laser beam. Lasers Surg Med 1986; 6(4):396–398.
7. Pogrel MA, Muff DF, Marshall GW. Structural changes in dental enamel induced by high energy continuous wave carbon dioxide laser. Lasers Surg Med 1993; 13(1): 89–96.
8. McCormack SM, Fried D, Featherstone JDB, Glena RE, Seka W. Scanning electron microscope observations of $CO_2$ laser effects on dental enamel. J Dent Res 1995; 74(10):1702–1708.
9. Longbottom C, Pitts NB. $CO_2$ Laser and the diagnosis of occlusal caries: In vitro study. J Dent 1993; 21(4):234–239.
10. Walsh LJ, Perham SJ. Enamel fusion using a carbon dioxide laser: A technique for sealing pits and fissures. Clin Prevent Dent 1991; 13(3):16–20.
11. Walsh LJ, Abood D, Brockhurst PJ. Bonding of resin composite to carbon dioxide laser-modified human enamel. Dent Mater 1994; 10(3):162–166.
12. Rauhamaa-Mäkinen R, Meurman JH, Luomanen M, Torkko H, Viherkoski E, Paunio I. Irradiation of human dental tissues with $CO_2$-, Nd:YAG-, and $CO_2$-Nd:YAG combination laser. Scand J Dent 1991; 99:470–475.
13. Hess JA. Scanning electron microscopic study of laser-induced morphologic changes of a coated enamel surface. Lasers Surg Med 1990; 10(4):458–462.
14. Quintana E, Márquez F, Roca I, Torres V, Salgado J. Some morphologic changes induced by Nd:YAG laser on the noncoated enamel surface: A scanning electron microscopic study. Lasers Surg Med 1992; 12(2):131–136.
15. Tagomori S, Iwase T. Ultrastructural change of enamel exposed to a normal pulsed Nd:YAG laser. Caries Res 1995; 29(6):513–520.
16. Bahar A, Tagomori S. The effect of normal pulsed Nd:YAG laser irradiation on pits and fissures in human teeth. Caries Res 1994; 28(6):460–467.
17. Jennett E, Motamedi M, Rastegar S, Frederickson C, Arcoria C, Powers JM. Dye-enhanced ablation of enamel by pulsed lasers. J Dent Res 1994; 73(12):1841–1847.
18. Cox CJM, Pearson GJ, Palmer G. Preliminary *in vitro* investigation of the effects of pulsed Nd:YAG laser radiation on enamel and dentine. Biomater 1994; 15(14):1145–1151.
19. Márquez F, Quintana E, Roca I. Salgado J. Physical-mechanical effects of Nd:YAG laser on the surface of sound dental enamel. Biomater 1993; 14(4):313–316.
20. Roberts-Harry DP. Laser-etching of teeth for orthodontic bracket placement: A preliminary clinical study. Lasers Surg Med 1992; 12(5):467–470.
21. von Fraunhofer JA, Allen DJ, Orbell GM. Laser etching of enamel for direct bonding. Angle Orthod 1993; 63(1): 73–76.
22. Cernavin I. A comparison of the effects of Nd:YAG and Ho:YAG laser irradiation on dentine and enamel. Aust Dent J 1995; 40(2):79–84.
23. Arcoria CJ, Lippas MG, Vitasek BA. Enamel surface roughness analysis after laser ablation and acid-etching. J Oral Rehabil 1993; 20(2):213–224.
24. Goodman BD, Gwinnett AJ. A comparison of laser- and acid-etched human enamel using scanning electron microscopy. Arch Oral Biol 1977; 22(3):215–220.
25. Kutsch VK. Dental caries illumination with the Argon laser. J Clin Laser Med Surg 1993; 11(6):323–327.
26. Hafström-Björkman U, Sundström F, de Josselin de Jong E, Oliveby A, Angmar-Månsson B. Comparison of laser fluorescence and longitudinal microradiography for quantitative assessment of in vitro enamel caries. Caries Res 1992; 26(4):241–247.
27. Palamara J, Phakey PP, Orams HJ, Rachinger WA. The effect on the ultrastructure of dental enamel of excimer-dye, argon-ion and $CO_2$ lasers. Scanning Microsc 1992; 6(4):1061–1071.
28. Arima M, Matsumoto K. Effects of ArF:excimer laser irradiation on human enamel and dentin. Lasers Surg Med 1993; 13(1):97–105.
29. Feuerstein O, Palanker D, Fuxbrunner A, Lewis A, Deutsch D. Effect of the ArF excimer laser on human enamel. Lasers Surg Med 1992; 12(5):471–477.
30. Moss JP, Patel BCM, Pearson GJ, Arthur G, Lawes RA. Krypton fluoride excimer laser ablation of tooth tissues: Precision tissue machining. Biomater 1994; 15(12):1013–1018.
31. Tocchio RM, Williams PT, Mayer FJ, Standing KG. Laser debonding of ceramic orthodontic brackets. Am J Orthod Dentofac Orthop 1993; 103(2):155–162.
32. Burkes EJ, Hoke J, Gomes E, Wolbarsht M. Wet versus dry enamal ablation by Er:YAG laser. J Prosthet Dent 1992; 67(6):847–851.
33. Li Z-z, Code JE, Van De Merwe WP. Er:YAG laser ablation of enamel and dentin of human teeth: Determination of ablation rates at various fluences and pulse repetition rates. Lasers Surg Med 1992; 12(6):625–630.
34. Niemz MH. Cavity preparation with the Nd:YLF Picosecond laser. J Dent Res 1995; 74(5):1194–1199.
35. Arrastia AMA, Machida T, Smith PW, Matsumoto K. Comparative study of the thermal effects of four semiconductor lasers on the enamel and pulp chamber of a human tooth. Lasers Surg Med 1994; 15(4):382–389.